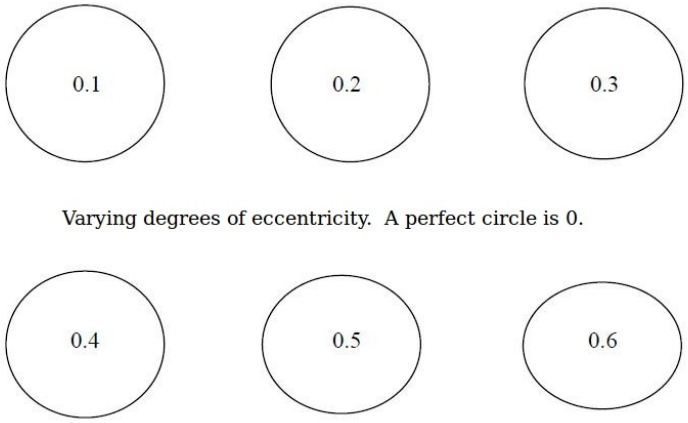
The Solar System: Collisions Gone Wild

by Michael Harwood (not an astronomer)

There are some very strange things in our solar system. Every planet is unique and peculiar in one or more ways, and so are most of the moons. This causes problems when astronomers try to explain the origin of the planets.

First a couple of definitions for non-astronomers. Eccentricity is a number, e, that describes how circular an orbit is. e ranges from 0.0 (being a perfect circle) to 1.0 (a straight line).



Varying degrees of eccentricity. A perfect circle is 0.

There are only two planets that demonstrate any significant eccentricity and they are Mercury and the dwarf planet Pluto with eccentricities of 0.206 and 0.248 respectively. Halley's comet has e = 0.967. All the planets except for Mercury and Pluto have orbits that are very close to circular orbits (e < 0.1), and you can see that even these two planets' orbits look circular to the naked eye.

The orbital plane is the plane in which all of the planets orbit the sun. We can either choose the sun's equatorial plane for this or the weighted average of all the planets' orbits. The latter is called "the invariable plane" and using this, all the planets orbit with 2.2° of this plane, with the exception of Mercury which orbits at an angle of 6° from it.

Now we'll look at each planet in turn ...

Mercury is the second densest planet after Earth. It is thought to have a massive iron core, even though the surface minerals show a distinct iron deficiency.[i] The large iron core was deduced from gravitational readings from the Messenger space probe in 2011-2015.

The problem is how to explain the massive core and the ultrathin crust which is so unlike the other rocky planets: Venus, Earth, Mars.[ii] The solution? one or more collisions with a massive object(s) which would strip the mantle and most of the crust. The chances of Mercury surviving these collisions is quite small[iii] so the collisions would have to meet a very narrow set of specifications on speed, angle, and timing; thus Mercury-like planets are expected to be very rare.[iv]

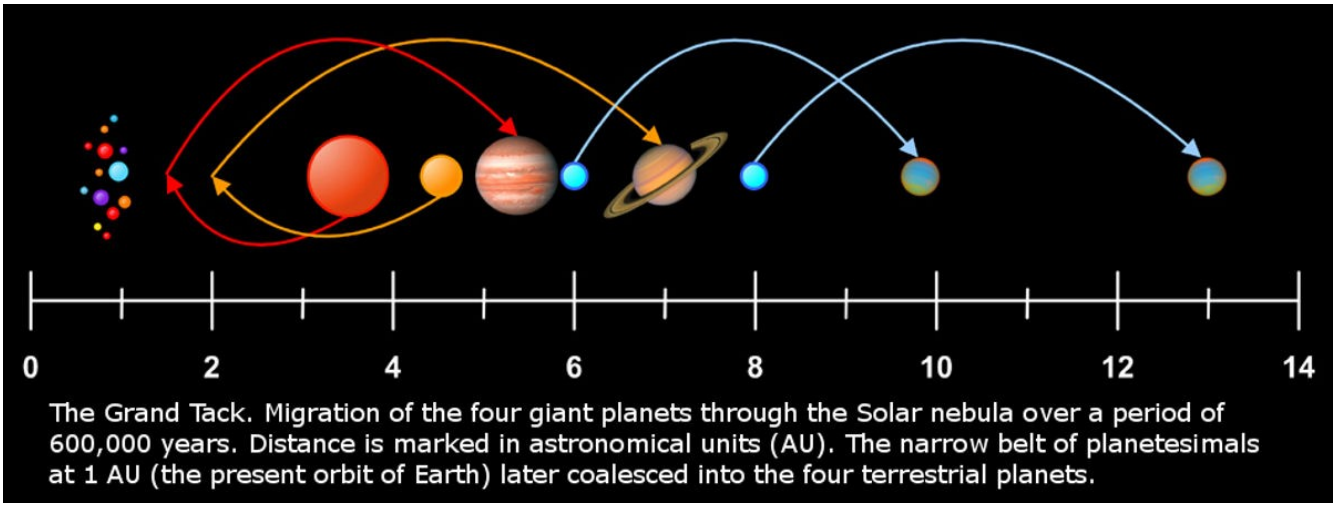
Venus is the hottest planet in the solar system. One of its peculiarities is that it rotates in the opposite direction to all the other planets; it rotates so slowly that it is hardly rotating at all. What could cause a planet almost the same size as earth to stop spinning one way and start spinning in the opposite direction? A head on collision with another large object is the standard solution. An alternative idea is that there were two smaller planets where Venus is right now and the two of them somehow collided and merged to form the present Venus.

Earth is chock full of anomalies. It has tons of water, plate tectonics, life, and oxygen atmosphere, and an enormous moon. The moon is so big relative to earth that it's almost a double planet system. You might be realizing that the solution to almost all anomalies in the solar system is to postulate massive collisions in the early history of the planet. Are massive collisions, other than the typical meteors that strike all planets, necessary to explain how Earth appears today? The water on the earth's surface could not have been there when the earth was formed – the planet would have been too hot. So the standard explanation is that it was bombarded with asteroids and some comets. Carbonaceous chondrites asteroids can contain up to 20% water. Even so, to get the amount of water in the oceans would take an enormous amount of asteroid bombardment.

The origin of the M**oon** is quite difficult to explain. The idea that the earth could capture a wayward moon that strayed too close to it has been discarded. The moon's orbit is so circular (e = 0.0549) that it's too unlikely to have happened, so the moon must have formed due to … yes, you guessed it, one or more massive collisions. The most recent theory is a single collision with a Mars-sized object (called Theia) that somehow managed to separate enough material to create the moon without completely destroying the Earth and ending up with another asteroid belt where we are now.

How about our reddish neighbour **Mars**? It is remarkable in that it is far smaller than it should be if it followed the standard planet formation protocol. It is only 10% the mass of the earth! Do we fall back onto the standard massive collision theory? No actually we don't; there doesn't seem to be evidence that a super impact removed most of its mass. We hypothesize something much more impressive, the Grand Tack Theory, which will be explained later. Has Mars then escaped the massive collisions that have transformed all of the other terrestrial planets? Actually no. Mars has a strange feature called the Martian hemispheric dichotomy. The northern hemisphere has a significantly thinner and less elevated crust than the southern hemisphere. It's very noticeable on maps of Mars. A single giant impact on the north or south pole of Mars is postulated as the probable cause of this dichotomy.[v]

The Grand Tack Hypothesis[vi] postulates that Jupiter and Saturn formed early and then started moving in towards the inner solar system. They swept up a lot of the material that would have gone into making Mars (but obviously they didn't get as far as Earth since we're here). Then these two planets “tacked” and “sailed” back out to where they are now, along with Uranus and Neptune which also moved out – see diagram below. This explains many oddities in our inner solar system[vii] as well as the small size of Mars, why the composition of Mars differs so much from Earth, and the composition of the asteroids (divided into two main types). You can probably imagine a couple of issues with this hypothesis: what makes them start moving? what reverses the motion (all the while keeping a circular orbit)? How did Jupiter avoid ejecting planets from the solar system as it moved around?



The Grand Tack. Migration of the four giant planets through the Solar nebula over a period of 600,000 years. Distance is marked in astronomical units (AU). The narrow belt of planetesimals at 1 AU (the present orbit of Earth) later coalesced into the four terrestrial planets.

(Source: https://www.everythingselectric.com/worlds-in-migration/)

Before we leave the four terrestrial planets and move on to the four gas and ice giants, there's another oddity: planetary magnetic fields. Mercury has one, Venus doesn't, Earth does, Mars doesn't. The four giant outer planets have magnetic fields, but Uranus' and Neptune's are significantly tilted (with respect to their planetary axes) and off centre.

After Mars comes **the asteroid belt** which, surprisingly, contains less mass than the Moon. We're not sure why it's there. The outer edge of the Asteroid belt is the Frost Line in the solar system. Beyond this, it's cold enough for water to remain frozen as ice. This allows giant gas and ice planets to form.

Leaving the rocky inner planets we get to the 4 gas/ice giants and the double dwarf planet Pluto.

Jupiter is 2½ times the mass of all of the rest of the planets combined and also has the fastest rotation Soon after the Juno space probe arrived in 2016, it made a surprising discovery: Jupiter's core is not dense and compact, but *dilute* and extending with no clear transition into the enveloping dense inner atmosphere. What could have caused this bizarre planetary core? The solution is a massive head-on collision with an unknown enormous planet! [viii] According to Chelsea Gohd, "the developing planet that collided with Jupiter must have been about 10 times the mass of the Earth, because 'smaller impactors cannot penetrate Jupiter's massive envelope', Liu said. Additionally, the collision must have been head-on, because if the object didn't hit Jupiter directly, it would slowly sink toward the center instead of destroying the planet's core, as it would have less impact energy." [ix]

Saturn has a number of very unique features. It has a lower density than water, so it would float on a giant ocean just like a piece of wood does. This combined with its fast rotation, makes it visibly squashed at the poles. It has a bright gorgeous ring system that is incredibly thin. The rings are 300,000 km wide, but less than 1 km thick. If the rings are scaled to the thickness of a normal piece of paper (ie. 0.1mm thick), the paper would have to be over 2.5 km wide. To my knowledge, there are no scenarios necessitating Saturn to suffer a collision from a massive object. Saturn is unique in this aspect, though collisions were probably involved in forming the moons and rings.

Uranus is unique in that it rotates on its side. It is also far colder than expected, being the only gas/ice giant that doesn't generate internal heat. The obvious cause for Uranus to be rotating on its side is a massive glancing collision with another icy planet that's about twice the mass of Earth. It's very difficult to model a collision where this works, let alone where its moons and rings orbit around the new equator.

Neptune has the fastest winds in the solar system (2000 km/hr). It seems to generate an unusual amount of heat, and its core is not as compact as expected. [x] A monumental head-on collision is a handy way to account for these phenomena (or aberrations).

Pluto, a dwarf planet, is also a double planet since both it and its massive moon **Charon** orbit a point <u>outside</u> of Pluto. Charon could have been formed through a gigantic collision of an object 30% the size of Pluto smashing into it, or it could be that Pluto and Charon already existed and had a collision before going off to orbit each other. The Pluto-Charon system shows us what the aftermath of a massive collision should look like: Pluto has the most eccentric orbit and the largest orbital inclination. However, it is difficult for a collision to produce Charon's highly circular orbit (with an eccentricity of only 0.0002) and to explain the weird orbits of Pluto's other moons.[xi]

We're now at the end of our journey, and every planet except for Saturn has had to have one or more devastating collisions in order to explain some peculiar feature. It might be worthwhile to consider a few problems with these numerous collision scenarios. Jupiter has a head-on collision and it rotates so fast that one day is only 10 hours, yet the head on collision of Venus results in a day that is 4 months long and it's rotating in the opposite direction. How does this happen? Furthermore, Jupiter has an axial tilt of only 3° <u>after</u> this massive collision.

The Martian impact has another problem: Mars' orbit is within 2° of the solar system's orbital plane. The massive impact on either the N or S pole should would have pushed Mars significantly above or below the orbital plane (such as Halley's comet which has an inclination of 160°).

Eccentricity also poses significant problems. Aside from Mercury, all the planets have orbits that are extremely close to being circular. It appears that these collisions had no effect at all on the planets' orbits. It is totally implausible that these massive collisions can reverse a planet's rotation, melt one hemisphere of Mars, or eject a moon so large that it's ¼ of the earth's diameter, and yet somehow leave the planet orbiting the sun in a circle.

The way to solve this conundrum seems to be speculating on some sort of mechanism to "circularize" the solar system's orbits. Now, we can check out this possibility by looking at the eccentricity of the 4000 exoplanets that we've discovered. Based on rough estimates, about half of the exoplanets have $e < 0.1$ and the other half have e between 0.1 and 1.0. This shows that while there are a lot of planets which have orbits similar to our solar system, there are just as many that range all over the place.

An interesting twist is that graphing eccentricity vs. number of exoplanets in the system shows a very strong correlation in which higher multiplicity of planets tends towards more circular orbits. Star systems with 5 or 6 planets always have $e < 0.3$ (There is no eccentricity data for stars with more than 6 planets. In fact, we have discovered only 4 stars which have 7 planets, one which has 8[xii], and one which might have 9). Does this mean that adding more planets to a star system somehow circularizes the orbits? No, not at all. A much simpler and thus more likely explanation is that the only way that planetary systems with large numbers of planets can survive long term is if the planets are already in circular orbits. When planets start interacting with each other (ie on non-circular orbits) they tend to either send smaller planets spiraling into the sun or eject them right out of the solar system.

The good news is that solar system astronomy is still a rapidly developing discipline. Many of the models and events that are described here did not exist a decade ago.

Is there any other plausible explanation for the current appearance of the solar system? Anything other than 8 massive impacts which had to occur within incredibly restrictive parameters and then two giant planets moving inwards and followed by four giant planets moving outwards?

Let's engage in a bit of fun speculation. Consider this: if you wanted to make a solar system that followed all the laws of physics, but also very clearly demonstrated that it was artificially created, what would it look like? Would it not have an extremely large number of planets each of which shows bizarre anomalies that require numerous fantastic coincidences to form? How would **you** organize a solar system that is intended to show intelligent design, yet one that still follows the laws of nature (so no triangular planets)? What would you do? Perhaps space the planets out according to some formula? *(cough, Titius-Bode law)* I think that an artificially designed solar system would look exactly like ours!

Can we consider whether the solar system is in fact an alien artifact? The main problem seems to be that we haven't found any signs of extraterrestrial life, let alone intelligence. The way to get around this is to do a *Gedankenexperiment*: cast natural skepticism aside and temporarily pretend that alien civilizations do exist. Is our solar system so strange and contrived that it's more sensible to ascribe its origin to a [hyopthetical] extraterrestrial intelligent power than numerous miraculous collisions of protoplanets? Are natural causes so implausible that artificial ones make more sense?
If this is so, then how about looking for other things that might be so improbable and so carefully designed that they might also be alien artifacts, the product of intelligent design? Candidates include
(i) DNA and the hundreds of nano- molecular machines that duplicate, transcribe, and correct it,
(ii) the cell which is far more complex and intricate than anything human beings have ever created,
(iii) and the universe itself. The fine tuning of the universe is so compelling that natural philosophers have been forced to invent a whole hypothetical untestable multiverse in order to dismiss its unsettling implications.[xiii]

The reader is free to draw his/her own conclusions (or not).

Written Aug 2020.

References

i Science Direct, “Mercury Surface” https://www.sciencedirect.com/topics/earth-and-planetary-sciences/mercury-surface

ii Cassis, Nikki, and Heather Beshears. “Planet Mercury a Result of Early Hit-and-Run Collisions.” ASU Now (Arizona State University) , 8 July 2014, https://asunow.asu.edu/content/planet-mercury-result-early-hit-and-run-collisions

iii “Hit-and-run origin for Mercury.” *Nature* **511,** 129 (2014). https://www.nature.com/articles/511129c

iv Redd, Nola Taylor. “How Did an Oddball Planet Like Mercury Form? ” Space.com, October 23, 2018 https://www.space.com/42225-iron-rich-mercury-planets-are-rare.html

v Wylie, Robin. “Giant Asteroid Collision May Have Radically Transformed Mars.” Scientific American, February 25, 2015. https://www.scientificamerican.com/article/giant-asteroid-collision-may-have-radically-transformed-mars/

vi Walsh, Kevin J. “The Grand Tack.”, SouthWest Research Institude, Boulder, CO. March 16, 2016, https://www.boulder.swri.edu/~kwalsh/GrandTack.html

vii Stephens, Tim. “Wandering Jupiter accounts for our unusual solar system.”, UC Stanta Cruz Newscenter, March 23, 2015, https://news.ucsc.edu/2015/03/wandering-jupiter.html

viii Byrd, Deborah. “Ka-bam! Signs of a giant impact with Jupiter”, September 5, 2019, https://earthsky.org/space/core-shows-possible-giant-impact-for-jupiter

ix Goh, Chelsea. “Jupiter's Strange Core May Have Been Forged by a Colossal Head-On Crash ”. Space.com, August 14, 2019, https://www.space.com/jupiter-strange-core-formed-by-collision.html

x Anderson, Paul Scott. “Why Neptune and Uranus are different ”, February 9, 2020 , https://earthsky.org/space/why-neptune-uranus-different-collisions

Helled, R., Nettelmann, N. & Guillot, T. “Uranus and Neptune: Origin, Evolution and Internal Structure.” *Space Sci Rev* **216,** 38 (2020). https://link.springer.com/article/10.1007/s11214-020-00660-3 (This has detailed information on Uranus and Neptune)

xi Wall, Mike. “Weird Orbits of Pluto's Moons Caused By Huge Collision ”, Space.com, October 09, 2013 https://www.space.com/23136-pluto-moons-orbits-giant-impact.html

xii “Open Exoplenet Catalogue” http://www.openexoplanetcatalogue.com/systems/

“HD 10180” https://en.wikipedia.org/wiki/HD_10180 (star with possible 9 planet system)

xiii Davies, Paul. “A Brief History of the Multiverse ”, New York Times, April 12, 2003. https://www.nytimes.com/2003/04/12/opinion/a-brief-history-of-the-multiverse.html?pagewanted=all

Hossenfelder, Sabine. “Why the multiverse is religion, not science.” July 09, 2019, http://backreaction.blogspot.com/2019/07/why-multiverse-is-religion-not-science.html